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Enforcing Emissions Trading Programs: Theory, Practice, and Performance

John K. Stranlund, Carlos A. Chavez, and Barry C. Field

Combining an analysis of the compliance incentives faced by firms in an emissions trading program, a comprehensive review of the enforcement strategies employed in Sulfur Dioxide Allowance and the Regional Clean Air Incentives Market (RECLAIM) programs, and a review of the compliance performance of these programs thus far, we are able to propose several practical guidelines for enforcing emissions trading programs. We stress the importance of prevailing market prices for emissions permits in determining compliance incentives, the importance of accurately measuring firms' emissions, and the importance of implementing enforcement strategies that remove the incentives firms may have to falsify emissions reports.

Introduction

Emission trading programs (also referred to as transferable or tradable pollution rights and cap-and-trade policies) are an innovative approach to controlling pollution that continues to gather support from policymakers and members of the regulated community. Conceptually, emissions trading programs are quite simple yet have very powerful implications. The typical design of a market-based system requires first that an environmental authority decide on an acceptable level of overall emissions. Permits consistent with that target, each of which confer the right to release a certain amount of pollution over some period of time, are then issued to polluting firms. Facilities may apply these permits to their own emissions, sell excess permits to other pollution sources, or purchase permits from other firms if their emissions exceed their permit holdings. If the coverage of the system is extensive enough and there are no serious institutional barriers to trading, an active market in emissions permits is established. By exploiting the power of a market to allocate pollution control responsibilities and by freeing facilities to choose the cheapest way to reduce their emissions, well-designed trading programs promise to achieve environmental quality goals more cheaply than traditional command-and-control regulations.¹

Despite the perceived advantages of market-based environmental policies over traditional command-and-control approaches, a number of authors have made it clear that the efficiency gains realized by emissions trading programs will depend on rates of compliance, which in turn will depend on the enforcement processes and activities pursued by those running the programs (Keeler, 1991; Malik, 1990, 1992; van Egteren & Weber, 1996). Others have provided conceptual analyses of how enforcement strategies for emissions trading programs should be designed to achieve high rates of compliance in a cost-effective manner (Beavis & Walker, 1983; Stranlund & Dhanda, 1999; Stranlund & Chavez, 2000). Almost no effort has been devoted to describing the enforcement practices and compliance performance of actual emissions trading programs.

Over the years, regulatory agencies have built administrative and legal systems to enforce the conventional command-and-control type of environmental regulation. Enforcement in a command-and-control world works by detecting and sanctioning performance that fails to meet the established standards. If a polluter has emissions in excess of the legal standard, the only way to move toward compliance is to reduce emissions toward the standard. But polluters in an emissions trading program have another option. If they have emissions in excess of their permit holdings, they can do two things to come into compliance: reduce emissions or purchase more permits. In an emissions trading system, therefore, regulators face a somewhat more complex enforcement problem. They must now focus both on emissions and on the behavior of firms in emission permit markets. This suggests that successful enforcement must now be undertaken in coordination with the permit markets.

In this article, we combine a conceptual model of compliance incentives in emissions trading programs with descriptions of the enforcement practices and compliance performance of actual programs to develop practical guidelines for enforcing these programs. The article proceeds as follows: We first present a model of the compliance incentives of firms in an emissions trading program. Then, we turn to an account of the enforcement strategies employed in the two most prominent market-based systems: the Sulfur Dioxide Allowance Trading program (SO₂) and the Regional Clean Air Incentives Market (RECLAIM) program. These programs have been described and discussed extensively (e.g., by Schwarze & Zapfel, 2000), but to our knowledge, no one has focused as clearly on their enforcement provisions. Armed with a conceptual understanding of the compliance incentives in emissions trading programs and knowledge of the how the SO₂ and RECLAIM programs are enforced, we evaluate the compliance performance of these two programs thus far. Taken altogether—theory, practice, and performance—we are able to develop several practical guidelines for enforcing emissions trading programs, which we lay out in our concluding section.

Compliance Incentives in a Transferable Emissions Permit System

To provide a context for an examination of the structure of the compliance incentives faced by firms in an emission trading system, we first briefly review the basic elements of the SO₂ and RECLAIM programs.

Basics of the SO₂ and RECLAIM Programs

The EPA's Sulfur Dioxide Allowance Trading Program, which is part of the U.S. Acid Rain Program implemented under Title IV of the 1990 Clean Air Act Amendments, was designed to reduce annual SO₂ emissions from fossil-fueled electric utility units by almost 10 million tons, nearly 50% of the 1980 emissions levels.² The SO₂ program was designed to run in two phases. Phase I operations began in 1995, affecting a total of 445 units. Phase II of the program, which began in the year 2000, extended the coverage of the program to include about 2100 units fired by coal, oil, and gas (U.S. Environmental Protection Agency, 2000). Units are allocated emissions allowances, each one of which authorizes its owner to emit one ton of SO₂

during a given year or any year thereafter. Overall emissions reductions are achieved by limiting the number of allowances in circulation. SO₂ allowances can be bought and sold or held for compliance purposes in future years. Sources cannot, however, borrow against future allocations for present compliance purposes.

The Regional Clean Air Incentives Market (RECLAIM) program contributes to the South Coast Air Quality Management District's (AQMD) efforts to achieve federal ambient standards for ozone and particulate matter in the Los Angeles airshed. RECLAIM was designed to reduce emissions of two pollutants, nitrogen oxides (NO_x) and sulfur oxide (SO_x), from stationary sources that released more than four tons of either pollutant in any year since 1990. By the end of the 1999 compliance year, RECLAIM covered 354 facilities (South Coast Air Quality Management District, 2001a).³ The RECLAIM program started operations in October 1993. By the year 2003, the program is expected to achieve reductions of 71% and 60% for NO_x and SO_x from 1994 levels by affected sources.

RECLAIM facilities are allocated RECLAIM Trading Credits (RTCs) for each year. Overall reductions in NO_x and SO_x emissions are achieved by reducing allocations of credits over time. Each credit allows the release of one pound of NO_x or SO_x during a specified compliance year. Facilities may sell or buy credits as they see fit.⁴ No banking is allowed in the RECLAIM program—facilities may not borrow credits from future allocations, and in contrast to the SO₂ program, they are not allowed to save credits for use or sale in future compliance years.

Although the RECLAIM program is an emissions trading program, it also includes emissions fees (South Coast Air Quality Management District, 2002, May 28). The applicable unit fees for both NO_x and SO_x emissions increase with a facility's level of emissions. Economists usually think of emissions taxes as an alternative method of incentive-based pollution control. In contrast, the RECLAIM taxes are clearly intended to help finance the program. However, as we will discuss shortly, these taxes probably have an impact on facilities' compliance incentives.

Compliance Incentives in an Emissions Trading Program

The overall goal of this article is to combine a conceptual understanding of compliance incentives in emissions trading programs with the practice and performance of enforcing the SO₂ and RECLAIM programs to propose practical guidelines for enforcing these programs. Stranlund and Chavez (2000) have recently proposed an economic model of compliance incentives in a competitive emissions trading program, which yields several conceptual principles for enforcing emissions trading programs. This section is based on their analysis.

They note that an important feature of the SO₂ and RECLAIM programs is their reliance on self-reporting of emissions from the facilities themselves.⁵ There are, then, two ways in which a firm could be noncompliant: (1) an emissions violation occurs when the firm fails to hold enough permits to cover its emissions, and (2) a reporting violation occurs when the firm transmits erroneous emissions data. To deter these violations, regulators have three basic instruments: (1) the monitoring of performance to identify incidences of noncompliance, (2) penalties for emissions violations, and (3) possible penalties for reporting violations.

Under these conditions, firms will choose how much pollution they will emit, how much they will report emitting, and how many permits they will hold. It is reasonable to assume that firms will make these decisions to minimize their expected costs, which consist of emissions control costs, receipts or expenditures from permit market transactions, and expected penalties from reporting and emissions violations. (A formal statement of a firm's decision problem is presented in the Appendix). Because the existing literature on enforcing market-based environmental programs has not yet been extended to dynamic environments, assume that emissions permits may not be banked for future use or sale.⁶ Suppose further that permits are traded in a reasonably competitive environment; that is, no facility can exercise power in the permit market, and transactions costs associated with trading permits are minimal. Furthermore, facilities do not bear emissions fees as in the RECLAIM program.

The enforcement strategy required to maintain complete compliance in this setting has two parts, both of which tie the enforcement variables to the prevailing permit price. Denote the market price of permits as p ; the probability that a source will get audited, which is assumed to be sufficient to discover a violation if one exists, as π ; a per unit fine levied for emissions violations as f , and a per unit fine for reporting violations as g .⁷ Assume that the penalties are applied automatically when violations are discovered. If the authorities wish to have complete compliance, there are two conditions that must be satisfied: (1) $p < \pi \times (f + g)$ and (2) $p < f$.

The first condition provides firms with the proper incentive to submit truthful reports of their emissions. To understand why, first note that the permit price is the marginal benefit of noncompliance—it is the unit cost that is avoided when a firm chooses not to hold enough permits to cover its emissions. Second, note that if a firm misrepresents its emissions it is because it is motivated to cover up an emissions violation rather than purchasing enough permits to be in compliance. Therefore, the marginal benefit of misrepresenting a violation is the foregone cost of being in compliance, which is the permit price p . If a firm's emissions and reporting violations are discovered, it faces the per unit penalty f for its emissions violation and the per unit penalty g for its reporting violation. The expected marginal cost of falsifying an emissions report is therefore $\pi \times (f + g)$. Hence, a firm will provide a truthful report of its emissions if the marginal benefit of under-reporting its emissions, p , is not greater than the expected marginal cost, $\pi \times (f + g)$.

Notice that the unit penalty for a reporting violation is not required to make sure that a facility has the proper incentive to submit accurate emissions reports. In fact, the SO₂ and RECLAIM regulations do not include explicit penalties for submitting false emissions reports.

Guaranteeing accurate emissions reporting is only useful insofar as it serves the primary goal of achieving complete emissions compliance so that every firm holds enough permits to cover its emissions. In fact, firms will not hold enough permits to cover their emissions unless they have the correct incentive to submit truthful emissions reports. To understand why this is so, suppose that $p > \pi \times (f + g)$ so that a firm is not motivated to provide a truthful report of its emissions.

Obviously, if $p > \pi \times (f + g)$, then $p > \pi \times f$. The permit price p represents a firm's marginal benefit of not holding enough permits to cover its emissions, whereas f represents the firm's expected marginal cost of holding too few permits. Since the marginal benefit of the emissions violation outweighs its expected marginal cost, the firm will choose to hold fewer permits than it needs to cover its emissions. This is one of the most important lessons conveyed by this model of compliance incentives—facilities in a transferable permit system will not have the proper incentive to be compliant unless the enforcement strategy they face also removes the incentive to submit falsified emissions reports.

Although obtaining accurate emissions reports is necessary to induce compliance, it is not sufficient: The enforcement strategy must also satisfy $p \leq f$. Given the proper incentive to provide a truthful emissions report, a firm that is in violation will report the extent of its violation and will then be assessed the per unit penalty f . Therefore, if the price of being compliant—the permit price—is less than or equal to the certain marginal penalty for emissions violations, each firm will choose complete emissions compliance. If not, each firm will emit more pollution than the number of permits it holds allows.

The enforcement strategy required to maintain complete compliance highlights the importance of the prevailing permit price in determining compliance behavior. In a reasonably competitive environment, the prevailing permit price completely summarizes each facility's marginal benefit of noncompliance. Thus, a firm's compliance incentives do not depend on anything specific about itself, including its initial allocation of permits, its scale of operations, details about its production and emissions-control technologies, or its costs of reducing emissions.⁸ This suggests an important principle for enforcing a competitive emissions trading program. Since firm-specific details are not important components of their compliance incentives, there is no reason for an enforcement authority to target its enforcement effort because it suspects that some facilities may be more likely to be noncompliant than others.⁹ This is important because sources in a market-based pollution control program will often be very different in ways that one might expect would influence their compliance incentives.

In imperfectly competitive environments, however, prevailing prices may not convey all the necessary information about facilities' marginal benefits of noncompliance. Chavez (2000) shows that when a firm can exercise power in a permit market, its compliance incentives also depend on the degree to which the firm can manipulate permit prices. He also shows that significant transaction costs may also cause firms' marginal benefits of noncompliance to deviate from prevailing permit prices.

It is likely that the emissions fees faced by RECLAIM facilities will have the same impact. Recall that these are per unit taxes that increase with a facility's level of emissions. When faced with an emissions tax, a facility in an emissions trading system has two reasons to be noncompliant: to avoid the cost of holding enough permits to cover its emissions, the marginal benefit of which is the market price of permits, and to avoid paying the emissions tax, the marginal benefit of which is the tax

rate. Thus, a facility's marginal benefit of noncompliance is the prevailing permit price plus the emissions tax rate. This suggests two aspects of the RECLAIM taxes that are important to keep in mind. First, when evaluating the compliance incentives of RECLAIM facilities, we must realize that the emissions tax they pay is an additional incentive to be noncompliant. Second, the differentiated tax rates suggests differentiated compliance incentives—since the larger sources of emissions pay higher fees, they have a greater incentive to be noncompliant.

Noncompetitive elements aside, the importance of current permit prices in determining compliance incentives also suggests an important principle for setting penalties in competitive emissions trading programs. Instead of choosing fixed unit penalties, it may be more effective to tie penalties to the prevailing permit price. Since an effective enforcement strategy for a competitive trading system calls for setting $p \leq \pi \times (f + g)$, fixed unit penalties would require that monitoring (as captured by the audit probability π) must keep pace with fluctuations in the prevailing permit price. This may be a difficult task for enforcement authorities working with limited budgets. Alternatively, marginal penalties could be tied directly to the prevailing permit price. Then, marginal penalties would vary with permit price fluctuations and serve to stabilize the monitoring requirement.¹⁰

Enforcing the SO₂ and RECLAIM Programs

Additional guidelines for enforcing emissions trading programs can be gleaned from analyzing the actual practice of enforcing these programs. At the simplest level, enforcement of any law is characterized by two components—monitoring to detect violations and assessing sanctions if a violation is found. In this section we describe these components of the SO₂ and RECLAIM programs.

Monitoring in the SO₂ and RECLAIM Programs

Since the goal of enforcing an emissions trading program is basically to reconcile a facility's permit holdings with its total emissions over some compliance period, monitoring to accomplish this goal involves keeping track of permit holdings and monitoring each source's emissions. In their essentials, the monitoring strategies of the SO₂ and RECLAIM programs are quite similar. Both programs have systems in place to track permit holdings. Emissions monitoring in both programs relies heavily on data generated and reported by the facilities themselves. To monitor emissions accurately and to minimize the opportunities facilities may have to falsify reports of their emissions, both programs impose rather stringent technological and process requirements.

All facilities in the SO₂ program are required to install continuous emissions monitoring systems (CEMS), or an equivalent device, to monitor their emissions. These systems are capable of providing a nearly continuous and very accurate account of the volume of emissions leaving a facility. A unit's CEMS sends the emissions data to the utility's Data Acquisition and Handling System (DAHS), which collects and records the necessary measurements and formats the information electronically into a quarterly report. These quarterly reports are submitted to the EPA electronically.¹¹ The process for generating reports and submitting them to the EPA

is fully automated, thereby minimizing the opportunities for tampering with the emissions data.

Monitoring by EPA officials is focused primarily on the facilities' emissions reports, as well as their testing and maintenance reports. The EPA subjects every emissions report to a series of reviews to verify its accuracy and to determine compliance. Audits appear to be done primarily of the source's reports rather than to consist of site visits, although the EPA may conduct site audits to inspect CEMS devices and review on-site operations and CEMS quality assurance records (U.S. EPA, 2002f, August 9).

RECLAIM facilities are also required to install and maintain specific monitoring and reporting equipment, but these requirements differ among types of sources. Specifically, NO_x sources are classified into four categories depending on emissions levels: major sources, large sources, process units, and equipment. SO_x sources are classified into three categories: major sources, process units, and equipment.¹² CEMS are required for all NO_x and SO_x major sources. Facilities in other source-categories are required to install monitoring systems that are cheaper than CEMS and that are correspondingly less accurate. NO_x large sources must install a device called a fuel flow meter. Process units and equipment categories for both NO_x and SO_x sources are required to use fuel flow meters or timers for emissions monitoring purposes. These devices are intended to produce periodic usage reports (amount of fuel or time of utilization), which, combined with equipment emission standards, are used to produce emissions reports (South Coast Air Quality Management District, 1991).¹³

Estimated emissions must be reported to the AQMD with specified equipment and software. Major sources must use a Remote Terminal Unit (RTU) to telecommunicate data to the AQMD Central Station. The RTU collects data, performs calculations, generates the appropriate data files, and transmits the data to the Central Station. Data for large sources and process units may be transmitted via RTU; alternatively, sources may compile the data manually and transmit them to the Central Station via modem.

At the end of each compliance year, RECLAIM authorities initiate audits for the previous year. Evaluations of reported data focus on ensuring the accuracy of the data and to check for incidences of noncompliance. Every single emissions report is audited in every single year. Each of these reviews apparently includes site visits to inspect equipment, monitoring devices, and operation records (South Coast Air Quality Management District, 1998, 2000, 2001a).

The most difficult task of enforcing an emissions trading program is obtaining an accurate and continuous measure of the emissions of each facility. Considering how much effort has gone into designing and maintaining the monitoring and reporting requirement in the SO₂ and RECLAIM programs, it is clear that policymakers are well aware of this.

Beyond the problem of estimating emissions, these data must be transmitted to enforcement authorities so that they can make a determination of compliance. Our conceptual understanding of compliance incentives in emissions trading pro-

grams and the reporting requirements of the SO₂ and RECLAIM programs is that both stress the importance of removing firms' incentives or opportunities to submit falsified emissions reports. The compliance model suggests that this can be accomplished by providing the correct incentives for truthful reporting, whereas the SO₂ and RECLAIM programs accomplish this with very stringent technology requirements. Either way, it is clear that enforcement of any emissions trading program will be effective only if enforcers are able to obtain truthful reports of emissions from regulated facilities.

Sanctions in the SO₂ and RECLAIM Programs

To provide a deterrent against noncompliance in a transferable permit system, facilities whose emissions exceed their permit holdings for some compliance period must face sanctions for these violations. The use of financial sanctions to punish noncompliance in the SO₂ program is quite close to the way penalties are applied in the model of compliance incentives described in the previous section. The unit penalty in the SO₂ program is unique in the fact that it is to be applied automatically. The penalty was set at \$2,000 per ton of excess emissions in 1990 and is indexed to inflation. Consequently, in 1998 the penalty was \$2,581 per ton of excess emissions. In addition to the monetary penalty, a noncompliant utility must offset the excess SO₂ emissions from its allowance allocation in the next year.¹⁴

The most significant difference between the enforcement strategies of the SO₂ and RECLAIM programs is the way sanctions for emissions violations are applied. Whenever an audit reveals a RECLAIM facility to have emissions in excess of its credit holdings, the facility is provided an opportunity to review the audit and to present additional data to further refine the audit results. If, after that review, the facility is judged to be noncompliant, the facility's allocation for the subsequent compliance year is automatically reduced by the total amount of excess emissions. In addition, the RECLAIM authorities may seek to impose administrative financial penalties. Noncompliant facilities may face penalties of up to \$500 for every 1,000-pound exceedance for every day the exceedance persists. If the annual average price of credits per ton of emissions reaches \$8,000, then, perhaps recognizing the greater incentive for sources to be noncompliant when credit prices are high, RECLAIM authorities can apply the \$500 penalty to every 500 pounds of excess emissions, effectively doubling the available penalty. Imposition of the penalty depends on the facts of a particular case, including the extent of excess emissions, apparent reason for the exceedance, and the vigor with which a source moves to correct its violation.¹⁵

It is clear that any financial penalties in the RECLAIM program will be imposed on a case-by-case basis rather than applied automatically as in the SO₂ program. Because of the resulting uncertainty that facilities must have about the consequences they will face if they are noncompliant, it is difficult to judge the deterrence value of the RECLAIM sanctions. We do know, however, that these sanctions provide less of a deterrent against emissions violations than if they were fixed and applied automatically. This is true because facilities will not base their compliance decisions on the maximum penalty, but on their expectations of what penalty may

actually be applied, which, of course, will be some lower value than the available penalty.

Compliance in the SO₂ and RECLAIM Programs

The enforcement strategies used in the SO₂ and RECLAIM programs have been quite successful to this point. The SO₂ program has apparently achieved a perfect compliance record. Compliance rates in the RECLAIM program have ranged between 85% and 95%.

Compliance in the SO₂ Program

The perfect compliance record of the SO₂ program is quite remarkable when compared to other environmental policies. Our conceptual understanding of the compliance incentives in emissions trading programs provides a partial explanation of why SO₂ facilities have always chosen to be fully compliant.¹⁶

One of the most important messages conveyed by our understanding of compliance incentives is that they depend critically on prevailing permit prices. The reason is simple: The permit price in a well-functioning permit system is a facility's marginal cost of acquiring enough permits to cover its emissions. When permit prices are high, facilities have a greater incentive to be noncompliant, and when they are low, facilities are more likely to be compliant.

Although price data from before the beginning of Phase I of the SO₂ program in 1995 suggests highly variable trading prices, by early in the first year of the program, SO₂ allowance prices had converged so that allowances were trading at roughly the same prices (Joskow, Schmalensee, & Bailey, 1998). Since then, current vintage allowance prices have ranged from a low of \$68 per ton in 1996 to over \$200 per ton in 1999.¹⁷ During 2000, allowance prices fluctuated quite closely around \$150.¹⁸

The marginal penalty for emissions violations in the SO₂ trading program has always been many times higher than prevailing allowance prices. This implies that the probability of detecting a violation necessary to achieve complete emissions compliance π , which is determined from $p \leq \pi \times (f + g)$, can be very low. For example, in 1998, prices for allowances ranged between \$100 and \$200 per allowance. In the same year, the monetary penalty for excess emissions was \$2,581 per unit. In addition, any excess emissions would have been offset in 1999, suggesting an additional per unit penalty for forfeited 1999 allowances equal to the present value of these allowances. Even if we do not account for this offset penalty, with a probability of detecting a violation as low as 0.08, $p < \pi \times (f + g)$ would be satisfied and sources would have the correct incentive to provide accurate emissions reports (even without a penalty for reporting violations). Given the effort expended on monitoring and the stringency of the reporting requirements in the SO₂ program, the actual probability of detecting reporting and emissions violations is probably much higher.

We have noted that as long as $p < \pi \times (f + g)$ is satisfied, emissions compliance is a simple matter of comparing the prevailing allowance price p to the certain unit penalty for emissions violations f . In the 1998 compliance year, for exam-

ple, $p < f$ was easily satisfied because the unit value of the SO₂ sanctions was between 13 and 27 times higher than prevailing allowance prices.

Our understanding of compliance incentives in emissions trading programs confirms Becker's (1968) seminal insight about the substitutability between monitoring for compliance and penalties for noncompliance. He pointed out that if monitoring is costly but setting penalties is not, the enforcement costs of maintaining compliance can be minimized by setting marginal penalties at arbitrarily high levels so that monitoring probabilities can be made arbitrarily small. There are very sound theoretical and ethical reasons for why this strategy is not very practical, and perhaps for these reasons, the strategy is not observed in actual practice.¹⁹ However, relative to prices for SO₂ allowances, the marginal penalty for emissions violations in the SO₂ program is very high. Thus, there is at least some precedence for setting penalties for emissions violations that are many times greater than prevailing permit prices. Within practical limits, therefore, the tradeoff between monitoring and penalties can be exploited to reduce monitoring effort or to increase the deterrence value of a particular monitoring strategy.

Because SO₂ sources may trade allowances dated for the future, we also have some indication of future allowance prices and, hence, future compliance incentives. Consider, for example, the results from the "7-year advance" auctions held by the U.S. EPA.²⁰ The clearing prices for these auctions were about \$168 a ton in 1999, \$55 per ton in 2000, and \$105 a ton in 2001. For the same years, the clearing prices in the spot auctions were about \$201, \$126, and \$174, respectively. This information suggests that allowance prices in the near future will remain well below the penalty for excess emissions. Therefore, it is likely that the perfect compliance record of the SO₂ program will persist for some time.

Compliance in the RECLAIM Program

The RECLAIM program has experienced noncompliant firms from its inception. In the early years, much of the noncompliance was attributed to misunderstandings of the required protocols (South Coast Air Quality Management District, 1998). In recent years, there has been a substantial amount of classic noncompliance, that is, firms failing to purchase sufficient credits to cover their emissions. In the 1998 compliance year, 27 out of 329 firms were noncompliant in NO_x emissions, whereas 31 out of 361 were noncompliant in 1999. In both years, all firms were compliant in SO_x emissions.²¹

Simple mistakes early on are easily explained as stemming from lack of experience with the RECLAIM rules. Explaining the more willful violations is not as straightforward. However, using the incentive approach that we've taken, a plausible explanation may start from the fact that effective prices for RECLAIM credits are high and increasing. Average prices for a ton of NO_x emissions during the first four calendar years of the program were always below \$250 but rose to \$451 during the 1998 calendar year and to \$1,827 in 1999. Average prices per ton of SO_x were under \$150 during the first four years of the program but rose to about \$300 in 1998 and to \$780 per ton in 1999. In 2000, prices for NO_x credits rose dramatically: For compliance year 1999 NO_x credits traded in 2000, the average price rose to \$15,369 per

ton, whereas for 2000 NO_x credits traded in 2000 the average price was \$45,609. Average prices for 2000 SO_x credits traded in 2000 also increased but to a more modest \$2,462 per ton (South Coast Air Quality Management District, 2001a).

In addition, because of the emissions fees that RECLAIM facilities face, their marginal benefits of noncompliance in the first 5 years of the program were much higher than indicated by credit prices. Relative to RECLAIM credit prices from 1994 to 1998, the fees are not small. Furthermore, these fees vary with the amount of pollution released. For annual emissions between 4 and 25 tons per year, the fees are currently \$171 and \$203 per ton of NO_x and SO_x, respectively. When annual emissions are between 25 and 75, the fees are \$272 and \$328 per ton of NO_x and SO_x, respectively. Finally, for annual emissions greater than 75 tons, the fees are \$409 and \$492 per ton of NO_x and SO_x, respectively. In 1998, the market price for credits for a ton of SO_x emissions was about \$300. Because of the SO_x emissions fee, however, a small source of SO_x faced an effective price of SO_x emissions of just over \$500 per ton, while the effective price for a large source was nearly \$800 per ton, about 2.67 times higher than the prevailing credit price at the time. Of course, with current credit prices many times higher than they were in 1998, the impact of the emissions fees on RECLAIM facilities' compliance incentives has eroded substantially.

RECLAIM violations may also result from the fact that the monetary penalties for emissions violations are not fixed or automatic. Recall that stated monetary penalties in the RECLAIM regulations are maximum administrative penalties and that actual sanctions are to be decided on a case-by-case basis. The uncertainty that RECLAIM facilities must then have about the consequences of their violations lessens the deterrence value of these sanctions; that is, facilities' evaluations of their expected marginal costs of noncompliance are probably substantially lower than if the sanctions were fixed and applied automatically. Because of the relatively low expected marginal costs of noncompliance that stem from the uncertainty of the financial sanctions they may face, and the high marginal benefits of noncompliance that are exacerbated by the RECLAIM emissions fees, it is quite possible that a number of RECLAIM facilities have decided that the incentives they face do not warrant their full compliance.

We are also somewhat pessimistic about the future performance of the RECLAIM program. Not only will credit prices be quite high for the 2000 compliance year, they will remain high into the near future. The average price for 2003 NO_x credits traded in 2000 was about \$13,800, and the average price for 2003 SO_x credits traded in 2000 was nearly \$3,000 per ton (South Coast Air Quality Management District, 2001a). If there is no off-setting change in the RECLAIM enforcement strategy, the compliance problems the program has experienced thus far, though relatively few in number to this point in time, may very well increase in the future.

Conclusions: Principles for Enforcing Emissions Trading Programs

Taken together—a conceptual understanding of the compliance incentives faced by firms in an emissions trading program, the practice of enforcing the SO₂ and RECLAIM programs, and the compliance performance of SO₂ and RECLAIM facilities thus far—several guidelines for enforcing emissions trading programs emerge.

Our approach to examining compliance incentives in emissions trading programs stresses the importance of the prevailing permit price. In a competitive trading environment, the prevailing permit price completely summarizes each facility's marginal benefit of noncompliance. A number of guiding principles follow from this observation. First, details about a firm's operations, such as its production and emissions-control technologies, are not important components of their compliance incentives. Therefore, there is no reason for an enforcement authority to target its enforcement effort because it suspects that some facilities may be more likely to be noncompliant than others, even though they may be quite heterogeneous. There is no evidence that SO₂ and RECLAIM officials pursue some sort of targeted enforcement strategy.

Unfortunately, in noncompetitive environments—those in which permit trades involve significant transaction costs, when a firm or group of firms can exercise power in a permit market, or when firms face differentiated emissions taxes as in the RECLAIM program—prevailing permit prices may not convey all the necessary information about facilities' compliance incentives. Furthermore, these complications may produce differentiated compliance incentives.

We have also made several suggestions for setting penalties in emissions trading programs. First, since permit prices have such an important influence on compliance incentives, to stabilize compliance incentives and corresponding enforcement strategies in the face of permit price fluctuations, unit penalties for emissions violations should be tied directly to prevailing permit prices. This suggestion may be particularly useful in the RECLAIM program, in which credit prices have risen rapidly over the last couple of years. Unit penalties that follow credit prices would offset the increasing incentive toward noncompliance that comes with higher credit prices.

Second, these penalties should be substantially higher than prevailing permit prices. Certainly, the perfect compliance record of facilities in the SO₂ program is due in large part to the fact that penalties in the SO₂ program have always been many times higher than going allowance prices.

Third, the application of penalties should not produce uncertainty for firms about the consequences of noncompliance. The fact that the unit penalty in the SO₂ program is fixed and applied automatically has probably been another contributing factor to the perfect compliance record of SO₂ facilities. On the other hand, we suspect that the determination of penalties on a case-by-case basis in the RECLAIM program produces uncertainty for facilities about the consequences of noncompliance and thus weakens the deterrence value of the RECLAIM enforcement strategy.

On the other side of the enforcement equation—monitoring for compliance—it is clear that a well-functioning emissions trading program requires continuous and reasonably accurate estimates of the emissions leaving each facility. The designers of the enforcement components of the SO₂ and RECLAIM programs addressed this difficulty by requiring emissions sources to install and maintain advanced emissions monitoring systems. Furthermore, our understanding of compliance incentives in emissions trading programs makes it clear that enforcement of any emissions trading program will be effective only if the incentive or opportunities for falsifying emissions reports are removed. As with generating accurate emissions data, the SO₂ and RECLAIM programs addressed this issue with very stringent technological and process requirements for submitting data to enforcement authorities.

Although it is true that our understanding of the theory and practice of enforcing emissions trading programs adds new insight into the problem, it is equally true that this exercise reveals critical areas in which our knowledge is lacking. Future research that addresses issues concerning the dynamics of compliance, monitoring accuracy, and the enforcement problems associated with implementing emissions trading programs in a wider variety of environmental policy problems than at present is needed to help refine existing enforcement strategies and to design enforcement strategies for new market-based policies.

The practice and theory of market-based environmental control has progressed quite far since they were first proposed more than 30 years ago. However, too little attention has been given to understanding the nature of the compliance incentives inherent in these programs and to the manner in which these programs are actually enforced. It is our hope that this work will help to bridge the gap between the practice and theory of enforcing market-based environmental policies and that it will help motivate policymakers and analysts alike to look for even more innovative ways to ensure that market-based policies can achieve environmental quality goals while conserving private and public resources.

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Appendix

The enforcement conditions presented in the text are derived by Stranlund & Chavez (2000) using a static model of a risk-neutral firm that operates under a competitive emissions trading program. The firm's costs of reducing emissions is summarized by $c(e)$, which is strictly decreasing and convex in its actual emissions e . The standard interpretation of $c(e)$ is as follows: Let e^0 be the firm's unconstrained level of emissions and let $\pi(e^0)$ be the firm's maximal profit in this setting. The cost of holding its emissions to $e < e^0$ is then $c(e) = \pi(e^0) - \pi(e)$.

Denote an emissions report as r . Let l_0 be the number of permits that are initially allocated to the firm, and let l be the number of permits that the firm holds after trade. Assume that permits trade at a competitive price p . An emissions violation occurs when a firm's emissions exceed the number of permits it holds ($e - l > 0$), and a reporting violation occurs when its actual emissions exceed its reported emissions ($e - r > 0$). Assume that a firm never reports that its emissions violation is greater than it actually is ($e - r \geq 0$), and it never reports that it is over-compliant ($r - l \geq 0$). These restrictions imply $e \geq r \geq l > 0$.

Given the per unit penalties, f and g defined in the text, if a firm reports an emissions violation, a penalty of $f \times (r - l)$ is imposed automatically. If a firm is audited and found to have under-reported its emissions, a penalty for the reporting violation, $g \times (e - r)$, is imposed, as well as the incremental penalty for its unreported emissions violation, $f \times (e - l) - f \times (r - l) = f \times (e - r)$.

The objective of a risk-neutral firm is to choose its emissions (e), its emissions report (r), and permit demand (l) to minimize $c(e) + p \times (l - l_0) + f \times (r - l) + \pi \times [g \times (e - r) + f \times (e - r)]$, subject to $e \geq r \geq l > 0$. The enforcement strategy presented in the text follows from the analysis of the Kuhn-Tucker conditions for this problem. A formal proof is available from the authors. Alternatively, one may consult Stranlund & Chavez (2000).

Notes

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¹ The idea that market-based pollution control policies can achieve environmental quality goals in a less expensive way than traditional command-and-control policies originates with Crocker (1966) and Dales (1968). Montgomery (1972) provided the first rigorous theoretical justification for the use of market-based policies. A number of economists have turned the theoretical literature into practical guides for policymakers (Hahn, 1989; Hahn & Noll, 1982; Tietenberg, 1985; Tripp & Dudek, 1989).

² A wealth of information about the U.S. Acid Rain Program, including the SO₂ Allowance Trading Program can be found on the Internet at <http://www.epa.gov/airmarkets/arp/>.

³ Facilities under RECLAIM are divided into two cycles with compliance schedules that are staggered by 6 months. Compliance years for Cycle 1 facilities run from January 1

through December 31, and Cycle 2 compliance years are from July 1 through June 30. Thus, the 1999 compliance year ran from January 1, 1999, to June 30, 2000.

⁴ There is a single spatial restriction on trading credits. Specifically, a facility in Zone 1 (the coastal zone) may only obtain credits from other Zone 1 facilities, whereas a facility in Zone 2 (the inland zone) may obtain credits from either Zone 1 or 2 [Regulation XX-RECLAIM, Rule 2005, (e)] (South Coast Air Quality Management District, 2001b, May 30).

⁵ Despite the prevalence of self-reporting requirements in the enforcement of environmental policies, only a few other authors have examined the role of these requirements, and all have done so in the context of enforcing standards (Harford, 1987; Malik, 1993; Kaplow & Shavell, 1994; Livernois & McKenna, 1999).

⁶ Future work that examines how dynamic choices involving permit banking, longer-term investments in production and pollution control technologies, and ongoing relationships between facilities and enforcers affect firms' compliance incentives would probably reveal ways in which enforcement strategies can be refined to exploit these dynamic elements.

⁷ Nearly all of the economic literature on enforcement sidesteps the problem of monitoring accuracy. Clearly, however, obtaining reasonably accurate accounts of firms' emissions will be a critical component of any market-based environmental policy. This is another important issue that future research should address.

Although one can imagine other penalty structures (assuming increasing marginal penalties is common in the literature), the assumption of constant marginal penalties is consistent with actual penalty structures in the SO₂ and RECLAIM programs.

⁸ This is not to say that these factors play no role in a firm's choices. They will obviously affect its choice of emissions. However, several authors have noted that these factors will not affect a firm's compliance decisions, that is, whether it submits a truthful emissions report or whether it holds enough permits to be compliant (Malik, 1990; Stranlund & Dhanda, 1999; Stranlund & Chavez, 2000).

⁹ In contrast, Garvie & Keeler (1994) demonstrate that enforcement of command-and-control emissions standards should monitor firms with high marginal abatement costs more closely than those with low marginal abatement costs.

¹⁰ For example, suppose that the marginal penalty for a reporting violation is chosen to be $g = \gamma p$, where $\gamma > 0$, and the marginal penalty for an emissions violation is $f = \phi p$, where $\phi > 1$ to satisfy the requirement that $p < f$. To satisfy $p < \pi \times (f + g)$, a constant audit probability $\pi > 1/(\gamma + \phi)$ will guarantee complete compliance, and is independent of fluctuations of the permit price. Because permit prices will fluctuate to some degree during a compliance period, in practice, penalties could be tied to some average price during the period. If there is a reconciliation period following each compliance year as in the SO₂ and RECLAIM programs, marginal penalties could be tied to the average price during this grace period.

¹¹ Other requirements include initial equipment certification procedures, periodic quality assurance and quality control procedures, and procedures for filling in missing data. The approach for estimating emissions when monitoring equipment is not working properly is designed to overestimate emissions to keep downtime of the monitoring systems to a minimum (U.S. EPA, 2002c, July 1; 2002d, July 1).

¹² Detailed descriptions of the types of sources in each category are contained in Regulation XX-RECLAIM, Rule 2011 (c), (d) and (e), and Rule 2012 (c) and (d) (South Coast

Air Quality Management District, 2001b, May 30). A 1996 audit of emissions revealed that major NO_x sources were responsible for 84% of RECLAIM NO_x emissions, while major SO_x sources represented almost 98% of total RECLAIM SO_x emissions (South Coast Air Quality Management District, 1998).

¹³ Maintenance and testing procedures for all monitoring equipment are required for each year. As in the SO₂ program, RECLAIM rules also include an upwardly biased approach for estimating emissions when monitoring equipment is not working properly.

¹⁴ To help facilities avoid these sanctions, facilities in the SO₂ program have 60 days at the end of each compliance year to acquire allowances if they have a shortfall, or to sell or save allowances if they hold more than they need (U.S. EPA, 2002b, July 1). RECLAIM facilities also enjoy a 60-day reconciliation period at the end of each compliance year, as well as 30-day reconciliation periods after each of the first three quarters of the year [Regulation XX-RECLAIM, Rule 2004 (b) and (c)] (South Coast Air Quality Management District, 2001b, May 30).

¹⁵ Consult Regulation XX RECLAIM, Rule 2004 (d) for the definition of violations, and Rule 2010 (c) for procedures for assessing administrative penalties. The AQMD may also impose additional permit conditions to prevent further violations [Regulation XX-RECLAIM, Rule 2010 (b), 1 and 2] (South Coast Air Quality Management District, 2001b, May 30).

¹⁶ It cannot explain, however, the significant amount of aggregate overcompliance in every year of the SO₂ program. During Phase I, aggregate emissions were between 23% and 39% lower than current allowance allocations. As a percentage of allowable emissions—the current allocation of allowances plus allowances saved from previous compliance years—aggregate emissions fell to only 30% in 1999 (U.S. EPA, 1996, 1997, 1998, 1999, 2000). This is due to the fact that the rapid increase in the stock of banked allowances has far outpaced the more modest decrease in the aggregate allocation of allowances. Since the model of compliance incentives in emissions trading programs does not allow for permit banking, it cannot explain aggregate overcompliance in the SO₂ program.

¹⁷ Information on allowance prices can be found at U.S. EPA, 2002e, July 1. The current vintage is defined as those allowances that can be used to cover current emissions. In other words, it includes allowances allocated for the current period plus banked allowances from previous compliance years.

¹⁸ One of the surprises of the SO₂ program is that allowance prices have been much lower than they were expected to be before allowance trading began. Explaining this has been a major focus of the literature (Burtraw, 1996; Ellerman & Montero, 1998; Ellerman, Schmalensee, Joskow, Montero, & Bailey, 1997, especially section VI).

¹⁹ Cohen (1999, section 3) and Macauley and Brennan (1998, section 3.3.2) discuss limits to setting arbitrarily high penalties, both with reference to enforcing environmental policies.

²⁰ Results of annual auctions can be found at U.S. EPA, “Acid Rain Program allowance auctions,” (2002a, July 1). As the name suggests, “7-years advance” allowances can first be used for compliance purposes 7 years into the future.

²¹ In aggregate, RECLAIM facilities have also been significantly overcompliant. Aggregate emissions of SO_x as a percentage of allowable emissions credits were about 70% in 1994, rose steadily to about 90% in 1998, and are expected to be around 92% for the 1999 compliance year. Similarly, in 1994, aggregate SO_x emissions were about 63% of allowable emissions, rising to 85% in 1998, and are expected to be about 99% of allowable emissions in

1999 (South Coast Air Quality Management District, 2001a). Since the model of compliance incentives focuses on achieving exact compliance, it cannot explain why some RECLAIM facilities have chosen to be overcompliant while others have been noncompliant.

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